The effect of environmental factors on wood characteristics

IV. Irrigation and partial droughting of Pinus radiata

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Introduction

In a previous study the effect of supplementary water on the wood characteristics of Pinus radiata D. Don was reported (Nicholls 1971a). The study material was grown near Adelaide, South Australia, where trees may be expected to be under some moisture stress during summer. Supplementary water was applied at the rate of 25 mm per week during summer and early autumn. The relief of water stress during the driest months of the year resulted in sizeable improvements in stem diameter increment and an increase in the proportion of thick walled cells associated with summer and autumnal growth.

An experiment was established at Canberra in 1954 in a nine-year-old stand of P. radiata (planted in 1945) as part of an investigation into suspected drought dieback (autumn brown top). Treatments applied were partial drought, normal precipitation and irrigation. Aspects of this study dealing with soil-water relationships and mortality due to summer drought have been reported (Waring 1971; Waring, in press).

Too little information is available on the influence of soil water on wood characteristics. In the present paper, data are presented following the examination of wood specimens from the Canberra experiment. These are of interest not only to complement the previous investigation with respect to the effect of supplementary watering but also because of the information provided by the partial droughting treatment.

Experimental Procedures

The study site was located in the Green Hills plantation 5 km west of Canberra. The site was previously covered with native grasses dominated by Stipa and Danthonia species and is situated about 3 km west of the Yarralumla Meteorological Station which provided the following data:

Elevation	550	m
Mean annual rainfall	645	mm (of uniform distribution)
Mean anual evaporation	1225	mm
Extremes of rainfall	306	mm 1944
	1100	mm 1950
Mean Maximum temperature (°C)	27.8	January
	27.2	February
	19.3	October
	22.5	November
	25.8	December

When the experiment was established the stand was growing vigorously and about to close canopy. The experimental plots were located on a moderate slope to ensure surface drainage. Each plot measured approximately 9.8 X 14.6 m, enclosing 24 to 28 trees at a nominal 2.4 m spacing. Three replications of three treatments were established using a latin square design:

(a) partially droughted, in which rainfall was prevented from reaching the ground directly
(b) controls which received normal rainfall, and
(c) irrigated, which received the equivalent of 12.5 mm of water each week throughout the year in addition to normal rainfall.

The partial droughting was achieved by constructing sloping platforms over the plots and covering them with bituminous sheeting. Rubber collars sealed the sheeting around the tree trunks and prevented stem flow from reaching the ground. Trenches about 45 cm deep were maintained around the platforms to sever surface roots, and water intercepted by the sheeting was directed away from the plots by metal gutters. The treatment became effective in October 1955.

On the irrigated plots, trenches about 30 cm deep were dug between the rows and maintained so as to contain about 1800 litres of water per plot.

Soil moisture cycles were followed by gravimetric analyses at 8 profile depths during 1956 and 1957. Results showed that the soil profile retained 18 cm of water at field capacity to a depth of 130 cm but only 12 cm of this was held as available moisture at tensions less than wilting point. Soils under the partial droughting treatment were maintained consistently near wilting point for the period whereas the controls accurately reflected variations in precipitation and were occasionally saturated.

During 1957 the living basal area on partially droughted plots stabilised at about 4 sq m per ha. Basal area on control plots rose to about 6 sq m per ha by 1960 and continued to fluctuate around that level. Irrigated plots achieved 10 sq m per ha and were still increasing when irrigation ceased in 1966. Waring (1971) attributed these consistent growth differences to variations in water availability.

Glasshouse experiments using surface soil ((0—7,5 cm) show that Pinus radiata seedlings respond to additions of nitrogen and phosphorus (Snowdon * unpublished) and analysis indicates that the surface horizon is a sandy loam of medium to low fertility..

Although irrigation was discontinued in June 1966, the droughting platforms were not removed but were not kept in repair. The sealing around the trees broke down progressively thus allowing stem flow (but usually not throughfall) to relieve a part of the water stress in some trees.

From each replication of each of the three treatments four trees were chosen to represent four diameter classes covering the range of diameter classes in the stand, that is 36 trees were sampled in all.

In August 1971, the 36 trees were sampled by the method of Brown (1958) to provide wood specimens approximately 50 mm square extending from bark to bark and including the pith. Specimens were taken at a nominal breast height and individual sampling heights were adjusted so that as far as possible specimens showed 21 complete growth rings. Specimens were located between branch whorls, and where necessary, at right angles to the direction of stem lean at the point of sampling. Before removal from the tree, the ends of each specimen were marked to show the direction of the tree axis. Specimens were wrapped in plastic and stored in a refrigerator pending examination.

Determinations of spiral grain angle and the collection of densitometric data were carried out according to techni-

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Table 1. — Means of cross-sectional dimensions at the positions of maximum and minimum density in selected growth rings from normal and treated *P. radiata* trees

Measuring position	Maximum density			Minimum density					
Tree type	Normal	Irrigated	Droughted	Normal		Irrigated		Droughted	
Growth ring number from pith	11	11	11	9	15	9	15	9	15
Radial cell diameter (γm)	15.3	19.2	14.6	38.5	34.3	41.7	38.9	36.8	27.6
Radial cell-wall Thickness (γm)	5.0	5.6	4.7	3.1	3.6	4.0	3.9	4,5	3.7
Tangential cell diameter (γm)	30.2	35.1	33.3	34.7	34.4	36.2	37.4	36.0	28.8
Tangential cell-wall thickness (γm)	7.6	8.1	7.5	3.1	3.4	3.7	3.7	4.8	3.8

ques described elsewhere (Nicholls 1971) a,b; Polge and Nicholls 1972).

At growth ring 11 for maximum density, and at growth rings 9 and 15 for minimum density, nine trees provided samples which were representative of the density means for each treatment. From these growth rings, 15 μm thick transverse sections were microtomed and examined, using an image shearing eyepiece in conjunction with apparatus similar to that proposed by Exley (1967). At the position of maximum or minimum density as required, 100 tracheids were measured at 600 magnifications and the means of lumen diameter and double wall thickness in the tangential and radial directions were recorded and used to prepare *Table 1.*

The determinations of densitometric features were carried out on material from the shorter of the two radii of each specimen to avoid compression wood. Angles of grain inclination for individual growth rings were expressed as the mean of values from both radii. Pieces to be used in the determination of densitometric data were treated with methanol in a Soxhlet apparatus to remove extractives.

Material from the growth ring adjacent to the pith was not examined because this ring is invariably incomplete and non-representative.

For each wood characteristic the data for each tree were tabulated according to growth ring number from the pith, and means for each ring were calculated for the three treatments. These are set out in *Figure 1.*

A series of 't' tests was used (treating each ring separately) to give an indication of the significance of differences between the means for the normal and irrigated trees, and the normal and droughted trees. The 5 per cent. level of significance was accepted as a real difference.

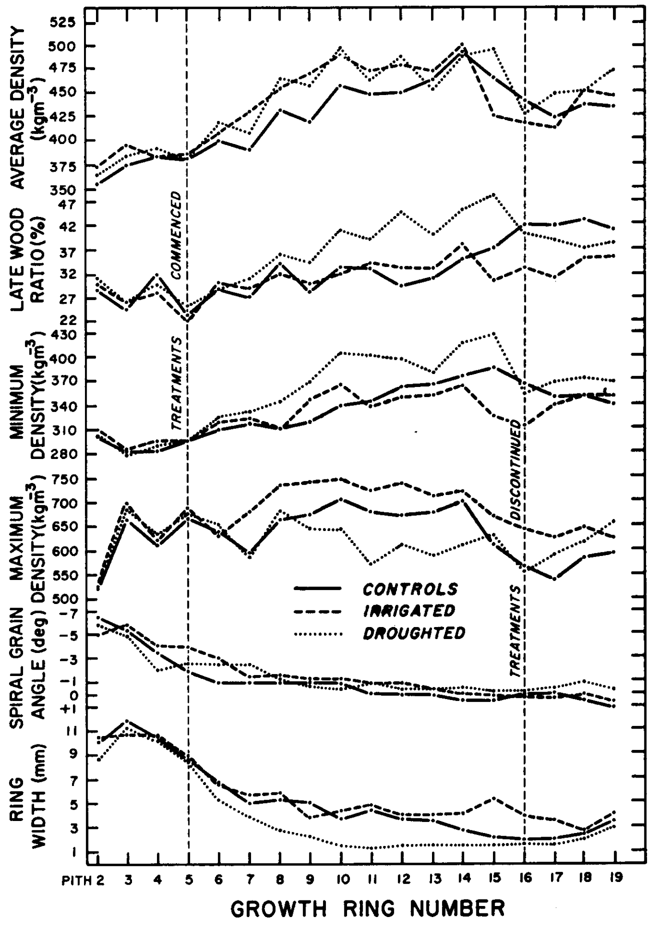

Figure 1. — The variation through successive growth rings from the pith of the means of ring width, spiral grain angle, maximum and minimum density, late wood ratio and average density. Means of 12 *P. radiata* trees grown in the Australian Capical Territory under each of three treatments, viz. controls, irrigated and partially droughted.

Results and Discussion

A pretreatment period prior to ring 5 (1954/55), the 11 years of treatment, and a short post-treatment interval from ring 16 (1965/66) onwards can be observed in *Fig. 1.*

Ring width

The pattern of variation is typical of plantation-grown *P. radiata* (see for example, Nicholls and Dadswell (1965), in which ring widths are at a maximum in the early growth rings before progressively decreasing under the influence of canopy closure and increasing competition for water and nutrients.

There is essentially no difference between the control trees and those subjected to either treatment in the interval from ring 2 to 5. The most immediate result of treatment is a decrease in growth rate for the trees subjected to partial droughting. Differences with respect to the control trees are significant from rings 8 to 14. The effect of supplementary watering on ring width is not consistent and although greater growth rates are recorded for these trees with respect to the controls, differences are only significant ($P < 0.05$) for rings 15 and 16. In the post-treatment period, except for the irrigated group at ring 17, the trees from both treatments exhibit growth rates which are very similar to that for the control trees. During the treatment period, cumulative annual increments for the partially droughted trees decreased 43.8 per cent. with respect to the controls while the irrigated trees show an increase of 18.5 per cent. The increased growth rate following irrigation supports the previous observation on the South Australian trees (NICHOLLS 1971a).

Based on samples from both normal and treated trees a correlation ($r = 0.92^{**}$) was obtained between ring width and the number of cells across the ring. The generally narrower growth rings resulting from the partial droughting treatment are therefore mainly due to fewer cells rather than to an average reduction in cell size.

From dendrometer measurements carried out on the experimental trees it was found that irrigation caused very little increase in growth during spring (ANON 1960). Therefore the bulk of the observed increase should occur in summer and autumn. The cessation of growth due to the onset of winter temperatures has been related to a limiting mean air temperature of 9° C (NICHOLLS and WRIGHT, 1976). For Canberra, this is estimated to take place on the average about the first week in May. Hence, over the treatment period, a relationship was investigated between summer and autumnal rainfall and the difference in ring width between the irrigated and control trees. A negative correlation with $r = -0.77^{**}$ was obtained for the period January to May. That is, the largest annual growth increases attributable to the irrigation treatment were observed when summer and autumnal precipitation was least.

What little water is received by the partially droughted trees would be through the foliage or from deep roots as suggested by Johnston (1964) when reporting on *P. radiata* in the same area.

However Figure 1 shows that the droughted trees are very unresponsive to seasonal climatic fluctuations which affect the control and irrigated trees.

Spiral grain

Grain angles for the three groups exhibit maximum 'left-hand' spirality at the second or third growth ring, then subsequenttly decrease with increasing age (ring number from the pith) through zero to small 'right-hand' angles. This pattern was observed by FIELDING (1967) in spiral grain studies carried out on *P. radiata* from the Canberra plantations.

The means for spirality for both the irrigated and partially droughted trees are not significantly different to that for the controls.

HARRIS (1969) produced evidence to show that grain spirality in the corewood (first ten growth layers) of this species can be explained in terms of spiral flow of metabolites arising from the phyllotaxy of the needle traces. In terms of this hypothesis it is difficult to see how levels of soil water would affect grain angles.

The present findings support other experience (NICHOLLS and FIELDING 1965; FIELDING 1967) that there is no consistent association between grain spirality and site factors affecting growth rate.

Maximum density

The mean for the control trees increases sharply from ring 2 to 3, more slowly to ring 14, declines from ring 14 to 17 and subsequently increases. This pattern has been observed in the juvenile wood of *P. radiata* from this area (NICHOLLS and BROWN 1971). The means for both groups of treated trees are quite similar to that for the control trees from ring 2 to 5.

The most immediate response to treatment is an increase in maximum density for the irrigated trees from ring 6 so that differences with respect to the controls are highly significant ($P < 0.01$) for rings 7 to 9 and ring 12. A similar increase following supplementary watering was also observed in the previous study on the South Australian material (NICHOLLS 1971a). The effect of the partial droughting is not apparent until growth ring 9 and produces a reduction in values so that the mean is significantly different to that for the controls at rings 11 to 14. Drought conditions in a particular growing season also resulted in a decrease in maximum density in the investigation by NICHOLLS *et al.* (1974). There are no significant differences between the controls and the treated trees in the post-treatment period.

Maximum density is generally recorded in the last-formed late wood and for *Abies grandis* POLGE (1965) found a highly significant negative correlation ($r = -0.89^{**}$) between maximum density and autumnal rainfall. On the other hand, NICHOLLS and WRIGHT (1976) were unsuccessful in attemps to relate maximum density to rainfall and temperature data using P. radiata clonal material. In the present case, relationships were tested between maximum density results for the normal trees, and values of rainfall and mean temperature averaged over a number of periods of one to two months, in the interval from December to May for each year from canopy closure (1955). No conclusive relationship could be found.

The position of maximum density in any growth ring is where cell-wall thickness is a maximum (NICHOLLS, unpublished data). LARSON (1969) observed that wall thickness appeared to be a function of the amount of photosynthate reaching each tracheid. Thus maximum density may be regared as an index of the period in the growing season of greatest import of photosynthates to the developing xylem. The amount will depend not only on the total quantity of photosynthate available for distribution but also on the net allocation after competition with other metabolic sinks within the tree.

The rainfall at Canberra is irregular, and autumnal growth, although possible after adequate falls of rain, is by no means the rule (FIELDING and MILLETT 1941, WARING 1971). Soil water is usually depleted by the relatively hot, dry summers and the trees can be under some degree of internal water stress during the autumn when late wood is normally formed. Metobolic activities such as photosynthesis and the translocation of carbohydrates are reducted according to the severity of water stress (SCHNEIDER and CHILDERS 1941). The soils under the partial droughting treatment were maintained consistently near wilting point whereas the irrigated trees received water equivalent to twice the mean annual rainfall. Thus the three treatments establish widely different levels of soil water availability, with the droughted trees under severe water stress, the normal trees experiencing an intermittent stress situation, and the irrigated trees little if any stress. The means for maximum density faithfully reflect these three magnitudes of stress with the irrigated trees greatest and the droughted trees least *(Figure 1)*.

The differences between the levels of available soil water associated with the three treatments would be generally much greater than the year to year differences at the time in the growing season when maximum density is recorded. Furthermore simple combinations of rainfall and temperature may not yield a precise measure of available soil water. Therefore it is not unexpected that differences between treatments are observed in spite of the unsuccessful attempts to establish relationship between climatic factors and maximum density data for the normal trees.

Table 1 shows that cell-wall thickness is greatest in the irrigated material and least in that subjected to partial droughting. Although all tracheids are flattened in the radial direction at the position of maximum density, radial cell diameter is markedly greater in the irrigated group compared to the normal trees. As noted by Zahner *et al.* (1964) radial flattening apparently occurs independently of assimilation of wall material in both treatments and is possibly regulated by auxin gradients and these would be expected to aid tracheid enlargement in the irrigated trees compared to the normal group.

Minimum density

There is a slight decline from ring 2 to 3 in the mean for the control trees followed by a steady increase to ring 15 and a subsequent decrease. This trend, at least in the juvenile wood, is similar to that recorded for *P. radiata* material from this area (Nicholls *et al.* 1974). The means for both treatments are similar to that for the control trees in the post-treatment period.

The partial droughting treatment results in an increase in minimum density values so that differences with respect to the controls are highly significantly different for rings 8 to 11. This finding supports the observation of Polge and Keller (1968) that low spring rainfall was associated with an increased minimum density. The effect of the irrigation treatment is not as clear. In the interval from ring 5 to 10, values tend to be larger than those for the controls with the means significantly different at ring 9. However from ring 11 to 16 the mean for the irrigated trees is less than that for the controls and the differences are significant at rings 15 and 16. There are no significant differences between the means for the controls and those for the treated trees in the post,treatment period.

The position of minimum density is usually observed in the early wood when cell diameter is at or near maximal and wall thickneess is minimal (Nicholls, unpublished data). However, because minimum density is sensitive to small changes in wall thickness. The position of minimum density is not always as clear or as constant as that for maximum density. Polge (1965) was unable to obtain any significant correlation between minimum density and climatic factors nor was there any success in this respect with the Victorian clonal study referred to above (Nicholls and Wright, 1976). In the present case relationships were tested between minimum density and rainfall and mean temperature data averaged over a number of intervals throughout spring for each year from the commencement of treatment. No conclusive relationship was found.

It may be noted that ring 15 (1964/65 season) had a very low seasonal rainfall and minimum density is greatest for the droughted trees and least for the irrigated group; that is, maximum change in minimum density is obtained from the supplementary watering in that growth period.

Table 1 shows that cell diameters are largest for the trees receiving supplementary water and smallest for the partially droughted group. This parameter obviously has a controlling influence on minimum density particulary noticeable at ring 15 for the partially droughted trees. Cell-wall thickness also affects density values, the most obvious example being that of the droughted trees at growth ring 9.

Tracheid diameter is governed in part by the amount of auxin reaching the cell during development, and the terminal shoots together with their elongating needles appear to be the major source of these auxins (Larson 1963). Minimum density should be an index of the period in the growing season when such terminal activity is most vigorous. The degree of activity is very dependent on the internal water status of the tree, which in turn is determined by soil water availability together with atmospheric conditions regulating transpiration (Zahner 1963). Internal water stress is seldom limiting in spring so that the effect of supplementary watering on minimum density is not large and is modified by year to year rainfall and temperature conditions. On the other hand, the effects of the partial droughting treatment invariably result in severe internal water stress and the influence on minimum density is evident throughout the treatment period.

Late wood ratio

This is the proportion of late wood in a growth ring assuming the early wood/late boundary is at the mid-density point (Nicholls and Brown 1971). The trend in the mean for the control trees generally shows an increase from the pith outwards. A variety of patterns has been recorded for this feature. The present case is simiar to the variation observed for *P. radiata* from this area by Nicholls and Brown (1974).

There are no significant differences in late wood ratio between the mean for the controls and those for the treated trees from ring 2 to 5. A marked increase in late wood ratio results from the partial droughting treatment such that values are significantly larger than those for the controls from ring 9 to ring 15. There is little early effect dues to supplementary water but at rings 15 to 17 the mean for the treated trees is significantly less than that for the controls. Apart from the mean for the irrigated trees at ring 17 there are no significant differences between the treated and control trees in the post-treatment interval.

The previous work on the South Australian trees (Nicholls 1971a) showed that the proportion of late wood was increased as a result of supplementary watering. Polge and Keller (1968) reported that the late wood was not modified by irrigation and Zahner *et al.* (1964) found that the percentage of late wood was the same in irrigated and droughted tres at comparable stem positions. On the other hand, Nicholls *et al.* (1974) noted that drought conditions were asciated with an increase in late wood ratio.

The loss of growth due to partial droughting is more marked in spring than in autumn (Waring 1971) so that the observed increase in late wood ratio is not unexpected in this material. It has already been noted that the irrigation treatment (see ring width) is most effective in summer and autumn and only produces an average 18 per cent. increase in annual growth rate. Therefore, on both counts, the influence of irrigation on late wood ratio will not be great, and the differences between the controls and treated trees will vary according to year to year climatic factors.

Average density

This characteristic is related to the other densitometric parameters as follows:

average density = late wood ratio (maximum density — minimum density) + minimum density.

The threes means increase from growth ring 2 to 14, decrease to ring 16 and subsequently increase.

There are no significant differences between the mean for the controls and those for the treated trees in either the pre-treatment or post-treatment intervals. Both treatments result in slight increases in average density. There are significant differences with respect to the controls for the irrigated trees at ring 7 and 9, and for the partially droughted trees at ring 10.

The variation patterns for average density result from the interaction of the patterns for the component parameters. Thus for the partially droughted trees the major influence is that of minimum density and late wood ratio. Conversely, variation in average density for the irrigated trees is mainly attributable to deviations in minimum and maximum density.

The observed increase in average density due to the irrigation treatment supports the findings from the study of the South Australian trees.

Conclusions

From an examination of breast-high wood specimens, it has been seen that ring width, as a measure of radial stem growth, is increased by the application of supplementary water and decreased by the partial droughting treatment. The improvement by irrigation occurs mainly during summer and autumn whereas the reduction from partial droughting takes place in spring.

Spiral grain angles are not affected by either treatment. The partial droughting causes severe water stress throughout the growing season increasing minimum density and late wood ratio and reducing maximum density. Irrigation on the other hand being most effective in summer and autumn mainly results in an increase in maximum density. The expression of these components in the complex of average density is a slight increase for both treatments.

The slight changes in wood quality introduced by the irrigation treatment would not be expected adversely to affect utilisation of the raw material. In so far as this treatment is concerned results generally confirm the findings of the previous investigation (Nicholls 1971 a).

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Summary

Wood specimens from a 26-year-old *Pinus radiata* stand were examined to show the effects of irrigation and artificial droughting on ring width, spiral grain angle and densitometric characteristics.. The treatments were maintained for 11 years. Ring widths were increased by the supplementary watering and decreased by the partial droughting. Neither treatment affected spiral grain angles but average density was increased slightly with respect to the controls both by irrigation and by droughting. In the irrigated trees the larger average density values were attributable to an increase in maximum density and in the droughted trees to an increase in minimum density and late wood ratio.

Key words: Wood characteristics, *Pinus taeda*, irrigation, droughting.

Zusammenfassung

In einem lateinischen Quadrat angeordnete Versuchs-Parzellen in einem 26jährigen *Pinus radiata*-Bestand wurden 11 Jahre lang entweder zusätzlich künstlich bewässert oder dadurch künstlich trocken gehalten, daß in die Parzellen Bitumen auf den Boden gebracht wurde. Durch zusätzliche Bewässerung wurden die Jahrringe breiter, durch teilweise Trockenhaltung schmaler. Dagegen vergrößerte sich die mittlere Holzdichte sowohl bei Trockenhaltung als auch bei Bewässerung, was bei den bewässerten Bäumen auf eine Erhöhung der maximalen Dichtewerte und bei den trocken gehaltenen Bäumen auf einen Anstieg der minimalen Dichtewerte sowie auf einen größeren Anteil an Spätholz zurückgeführt wird.

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